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COLLEGE,

THIRTY-SIXTH

ANNUAL REPORT

OF THE

DIRECTOR

OF

THE ASTRONOMICAL OBSERVATORY

OF

HARVARD COLLEGE.

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BY

EDWARD C. PICKERING.

PRESENTED TO THE VISITING COMMITTEE, NOVEMBER 10, 1881,
AND LAID BEFORE THE BOARD OF OVERSEERS,
JANUARY 11, 1882.

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1882.

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ASTRONOMICAL OBSERVATORY COLUMBIA COLLEGE NEW YORK

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THIRTY-SIXTH

ANNUAL REPORT

OF THE

DIRECTOR OF THE ASTRONOMICAL OBSERVATORY OF HARVARD COLLEGE.

1880–81.

To the President of the University:

Sir, — The present condition of the Harvard College Observatory furnishes a test of an opinion expressed in some of its recent annual reports, namely, that any addition to the resources of a scientific institution already supplied with the funds needed to keep it in working order will prove an advantageous investment. Such a sum is directly applicable to the extension of scientific inquiry. A similar gift to establish a new institution, or to support a feeble one, will be largely consumed in the mere preparation for such inquiry, and the head of the institution must spend much of his time in routine work, even if he is not required to devote a large part of his energies to teaching, as well as to research.

The proper division of labor, and the continuous use of apparatus, are advantages as important in science as in the arts. These advantages are possessed by a liberally endowed observatory as they are by the factory of a rich proprietor, who can afford any immediate expense required to secure the most abundant returns. It seldom happens that the endowment permits the use of the instruments to their full capacity. Until this point is reached, great results may always be expected from a slight increase of income.

The subscription raised in 1878 for the support of the Observatory for five years has given it for that time a much improved position for conducting researches. Many of the contributors to

the fund paid their subscriptions in full at the outset, and the Observatory thus acquired a large balance to the credit of its account with the University, which will of course progressively diminish until the five years have expired.

One of the most important advantages resulting to the Observatory from this temporary enlargement of its resources consists in the increased number of its assistants, which is now sufficient to allow the work of each to be more advantageously directed than was previously possible.

The observations with the large equatorial and meridian photometer are made by Mr. Searle, Mr. Wendell, and myself. Messrs. Cutler and Eaton assist in recording these observations and in their reduction. Miss Farrar and Mrs. Fleming also take part in the reductions. The meridian circle remains in the charge of Professor Rogers, who is aided in the observations by Mr. Brown, and in their reduction also by Mrs. Rogers and by Misses Saunders, Bond, and Winlock. The time-signals are in charge of Mr. Edmands, assisted by Mr. Chandler. These gentlemen and Mr. Howard are making the naked-eye observations of northern stars. The meteorological observations are ordinarily made by Mr. Searle, who also has charge of the accounts, correspondence, &c., and has devoted much time to work connected with the revision and publication of the equatorial observations. The compilation of the bibliography of the variable stars, and the computation of cometary orbits as noted below, are conducted by Mr. Chandler.

Three instruments, the equatorial, meridian circle, and meridian photometer, have been kept actively at work during the past year. The last of these instruments has proved so satisfactory that a large one is being constructed to carry on observations of stars too faint for the present instrument. The new photometer will have object-glasses four inches in diameter, and will be capable of measuring any star brighter than the tenth magnitude. It is expected that such measurements will form a part of the permanent routine work of the Observatory. The relation of a meridian photometer to other photometers resembles that of a transit instrument to a sextant. There are the same advantages of rapidity, ease of reduction, and probably of precision. On the completion of the new photometer we shall have the same advantages for measuring the light of any star that an observer would of

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finding its position if he possessed the only transit instrument in existence. It is hoped that the use of this instrument will become more general when its advantages are appreciated. I understand that a distinguished German astronomer is planning a photometer for similar work, and at his request a description of the instrument used here has been forwarded to him.

The work of these various instruments will now be considered. That of the large telescope may be classified as below, with reference to the principal objects observed.

Eclipses of Jupiter's Satellites. — One hundred and fifty-three of these eclipses have been observed photometrically, sixty-four during the past year. One improvement has been introduced by which the number of settings may be nearly doubled. A single observer can make but three settings a minute, or one in twenty seconds. With an assistant to record, the time is reduced to about nine seconds. This time has been reduced to five seconds by the employment of two assistants, one of whom reads the photometer circle, while the other records and observes the time by the chronometer. As the observer does not remove his eye from the eye-piece, it is probable that the accuracy of the observations will be increased, and the satellite followed nearer to the point of disappearance.

Objects having Singular Spectra. — The search for these objects has been much interrupted by the pressure of other work. Only perfectly clear nights when the moon is absent are available, and these rarely occur at certain seasons of the year. The general survey of the heavens with a telescope of four inches aperture has been completed from twenty to twelve hours of right ascension. The observations during the summer on the remaining eight hours were so much interrupted by the long twilight and other causes that it was deemed best to reserve this work for another season. The most important result of this search has been the discovery of the peculiar spectrum of the star Ll. 13412. Three bright lines were found having wave-lengths of 545, 486, and 466 millionths of a millimeter. The second of these lines probably coincides with the F line of hydrogen. The other two were unexplained until Dr. Konkoly, in "The Observatory," IV. 257, described the spectrum of Comet 1881 III. (the Great Comet), as containing the five lines 560, 545, 515, 472, and 468. Three of these, the first, third, and fourth, are the usual cometary lines;

the other two appear to be coincident with the lines of Ll. 13412. Accordingly, while other comets have a spectrum identical with that of the stars of Secchi's fourth type, and apparently largely composed of carbon, this comet contains a substance as yet unknown, which one star only is as yet known to contain. The bright-line stars in *Cygnus* and in *Sagittarius* also give the line 467, but differ in the position of the other lines.

Another interesting discovery is that the star *L²Puppis* has a banded spectrum. This star is more than forty-four degrees south of the equator, and at the time of observation was less than two degrees above the horizon.

Two stars were found, one in *Puppis*, the other in *Ursa Minor*, which from their color and spectrum were at once thought to be variables of long period. These predictions were verified by observation, and a very rapid method of discovering variable stars is thus suggested. An announcement of the last of these discoveries was telegraphed to the Astronomische Gesellschaft as an example of the cipher code referred to below.

The spectra of all the stars north of —40°, marked as red or colored in the Uranometria Argentina, have been examined in the large telescope. In most of them no peculiarity of spectrum could be detected. From the remainder, and from some miscellaneous sweeping for such objects, a list of about eighty stars having banded spectra has been compiled and published.

Variable Stars. — The photometric study of the stars *β Persei* and DM. 81° 25, proposed in my last report, has been carried out. The number of comparisons made of *β* and *ω Persei* was 2,748, six hundred during a single night. On this occasion the observations were continued almost without intermission from a quarter of seven in the evening to half past three in the morning. In like manner, 3,276 comparisons of DM. 81° 25 and 26 were made on five evenings. Nine hundred settings were obtained during one night. The probable error of a single minimum determined in this way is only about 1.3 minutes.

Comets. — This Observatory has taken an important part in the early distribution of circulars relating to the comets recently discovered, by defraying the cost of telegrams, and by furnishing the necessary observations and computations. In co-operation with the Dun Echt Observatory and the Science Observer, circulars have been distributed in Europe and America, giving an

early announcement of the elements and ephemerides of the five new comets discovered in the first ten months of 1881. The average interval between the time of announcement of the comet and the issue of the circular has been less than a week. The interval between the last of the observations needed to determine the orbit and the time of telegraphing the elements to Europe has been less than two days. The computations have been generally made by Mr. Chandler, who has not hesitated, whenever necessary, to continue them through the entire night. No important error has occurred in their telegraphic transmission to Europe, by means of the ingenious cipher code devised by Messrs. Chandler and Ritchie. These preliminary orbits proved sufficiently accurate for the purpose for which they were intended. That of the Great Comet of the year (Comet 1881 III.), was published within four days of the first appearance of the comet in the northern heavens, and agreed more nearly with observation than any other published elsewhere for some time. This agreement was due to the use of an early observation made at Rio. Barnard's Comet was not found in Europe until the publication of the ephemeris computed here. Denning's Comet was early suspected by Mr. Chandler to be periodic. Elliptic elements were computed by him; but a later mail showed that he had been preceded by Dr. Schulhof of Paris in this work.

The use of the large telescope in the observation of comets has not, in general, been allowed to interfere with the other work of this instrument, except when early observations were needed for the determination of their obits. Almost all of the observations were made by Mr. Wendell, many of them late in the night, when the telescope was not otherwise occupied. Comet 1880 IV. was observed on twenty-nine nights; Comet 1881 II., on two; Comet 1881 III., on forty-three; Comet 1881 IV., on fifteen; Barnard's Comet 1881, on ten; and Denning's Comet 1881, on eight.

Some miscellaneous measurements have also been made of these comets, particularly of Comet 1881 III. The form of this comet's tail was measured, and the brightness of portions of it at various distances from the head.

Meridian Circle. — During the past year observations have been made on 250 days. This number is distributed by months as follows: —

	Month.	No. Days.		Month.	No. Days.
1880.	November . . .	26	1881.	May	20
1880.	December . . .	21	"	June	18
1881.	January	24	"	July	22
"	February . . .	18	"	August	12
"	March	17	"	September . . .	23
"	April	24	"	October	25

The whole number of observations made during the past year is as follows: —

		No. Obs.	Total No. Obs.
Polaris.	Upper Culmination	122 . . .	
Polaris.	Lower Culmination	110 . . .	232
Sun.	Vernal Equinox	31 . . .	
	Autumnal Equinox	45 . . .	
	North Solstice	13 . . .	
	South Solstice	15 . . .	158
	Fundamental Stars		1999
Polar Stars.	Upper Culmination	293 . . .	
	Lower Culmination	170 . . .	463
Miscellaneous	. . . . .		350

The observations for the determination of the horizontal flexure by means of the collimators have been continued throughout the entire year as often as the atmospheric conditions have been favorable. The whole number of observations is fifty-eight. It was stated in the last report that the horizontal flexure for January of any year had been found to be about 0″.6 greater than for July of the same year. Since that time the values of this function derived from the fundamental stars observed have been computed for the years 1876 and 1877. We have now, therefore, sufficient data to determine the reality of this apparent variation. The values given below represent the difference between the value of the correction described as horizontal flexure for the mean of the months of January and December of any year and for the month of July of the same year both from the fundamental stars and from the collimators.

From the Fundamental Stars.		From the Collimators.	
$\frac{\text{Jan.}+\text{Dec.}}{2}$ — July	Δ Ra.	Jan. — July	Δ Ra.
	″		″
1872	+0.64	1879	+0.73
1873	+0.39	1880	+0.56
1874	+1.09	1881	+0.48
1875	+0.73		
1876	+0.14		
1877	+0.71		
1878	+0.62		
Means	+0.62		+0.59

The action of temperature upon the screws by which the two halves of the tube of the telescope are joined to the cube of the circle is suggested as the probable cause of this difference. Observations with the long collimator for the determination of the variation of the instrumental constants of the instrument have been continued throughout the year. For the most part there are two series during each day on which stars have been observed. During the autumn and winter, the image of the concentric rings, or the focus of the collimator, remains remarkably steady; but during the summer, it has been found necessary to limit the observations to the evening and to the early morning hours. As a further check upon the variability of the index-error of the circle, some experiments were made with the reserve level of the Russian transit; this method, however, proved unsatisfactory. A level of the form invented by Mr. John Clark was ordered of Fauth & Co., and was mounted upon the cube of the telescope in May. The use of this instrument has been limited to the determination of the variability of the level of the telescope and of the index-error of the circle. A definitive opinion of the value of this method of detecting changes in the position of the zero of the circle must be deferred till the value of the index-error has been derived from the observations of Polaris. According to present indications the level gives somewhat better results than the long collimator. At present the observations are arranged for the detection of changes occurring between the morning and evening hours.

A decided improvement in the performance of the Standard Clock, Frodsham No. 1327, has been maintained since its removal to the cellar of the building, as is shown below in the account of the Time Service. The extreme variation of the thermometer placed within the room and read through a glass window from the outside has been 8°. Comparisons of this clock with the mean-time clock at Waltham have been continued as before by means of the line of telegraph erected for the purpose.

The investigation of the errors of the fixed circle of the telescope for each degree was completed in August. A metal plate having an arc of 15° subdivided to 5′ was used for the investigation. It was attached to the frame which carries the microscopes opposite the circle to be examined. The frame proved to be capable of revolution with no sensible disturbance of the focus of

the microscopes. Each 15° of the fixed circle was compared with the constant arc upon the plate. Two series, one in May and the other in August, show a good agreement. The maximum error of any space was found to be about 1″.4, and the accumulated systematic error for 180° does not exceed 1″.3. The errors of the single degrees were found by comparing each degree with the first degree of the metal plate. From the provisional reductions it appears that the accidental errors of division rarely reach 1″ and that with two or three exceptions they never exceed 1″.3. The investigation is to be completed by an examination of each space of 5′.

Observations of certain stars were made at the request of Professor Davidson of the United States Coast Survey, of Professor Hall of the Naval Observatory, and of Captain Tupman of the Greenwich Observatory. Two observations were made of Comet 1881 III., and a special series of 280 observations was made for the purpose of ascertaining whether the telescope moves in a vertical plane during its revolution.

The chronograph sheets for 1880–81 have been read off to July of the current year. Since the last report, considerable progress has been made in the reduction of the zone observations. In the preliminary reductions of the fundamental stars, the observations of a few stars were found to indicate persistently a disagreement with the fundamental positions of Publication XIV.

By comparing the separate values of $(\Delta T+m)$ and of the equator-point correction for each date with the mean values of these functions for the same date, a list of stars showing substantially the same discordances from year to year was made out. From this list twelve stars in right ascension and forty stars in declination were selected for special examination. A list of the resulting corrections to the positions in Publication XIV. was submitted to Professor Auwers, with a request for instructions in regard to the proper course to be pursued in this case. He has subsequently authorized, on behalf of the Council of the Astronomische Gesellschaft, the use of the provisional corrections already found. The actual determination of the definitive values of $(\Delta T+m)$ and of the equator-point correction has been unavoidably delayed by this inquiry.

The right ascension constants have now been determined for the entire series from 1870 to 1879, and the declination constants

have also been found for the same time, except for the year 1871–72. The computation for this interval is nearly completed.

The entire number of dates, for which the constants have been determined, is 1,263. The tabular reductions to apparent place and the refractions have been completed for the entire series of zone observations. The reductions have been made for intervals of twenty minutes in right ascension and two degrees in declination. The whole number of days for which these computations have been made is 633, and the number of individual reductions is about 12,000.

Meridian Photometer. — The work originally proposed for this instrument of measuring on three nights the light of each of the naked-eye stars visible in this latitude was essentially completed August 25, 1881. The observations will be continued during another year, as the necessary delay for reduction and publication will not thereby be greatly increased. Of the four thousand stars in our catalogue, about fifteen hundred have been selected for re-observation on three nights each. We shall thus obtain at least six observations of these stars, which include all those brighter than the fourth magnitude, all those used in the principal nautical almanacs as standards, and all those of which the first measures proved discordant. About seventy-six thousand measures have been made in all; thirty-six thousand since November 1, 1880.

From a discussion of the upper and lower culminations of a hundred circumpolar stars, the law of atmospheric absorption has been deduced, and the corresponding correction for each of the stars observed determined. All the readings have been reduced to magnitudes, corrected for the difference in transparency of the prisms, the mean taken when the stars are completed, the residuals derived, and the probable error deduced. This work has also been in a great measure checked and entered in the sheets of copy ready for publication.

A comparison of the photometric observations with those made by the naked eye is much to be desired. The Uranometria Argentina furnishes the means of doing this with the southern stars, but extends only to 10° north. Accordingly, all the stars in the Atlas Coelestis Novus of Heis north of the equator, and brighter than the sixth magnitude inclusive, are being measured by the eye, aided, when necessary, by an opera-glass. Each star is to be measured by three observers, who are to compare it with two stars

in the vicinity of the pole, one being a little brighter, the other a little fainter. The interval between the two is supposed to be divided into ten parts, and the brightness of the star to be measured is estimated in terms of this interval. The standard stars, one hundred and fifty-seven in number, include all stars brighter than the second magnitude, and those between 60° and 75° north, which are used in determining the atmospheric absorption. The total number of comparisons required for this work is about nine thousand, of which nearly a quarter have already been made.

Time-Signals. — The distribution of time-signals continued in charge of Mr. F. Waldo until June 1, and since then Mr. Edmands has assumed their care. Special attention is now given to keeping the error always small, instead of reducing it to zero at 10 A. M. By graphical methods, the accuracy of the determination of the error during long periods of cloudy weather has been much increased. It is believed that the error rarely exceeds two tenths of a second in clear weather, and four tenths when cloudy, and that the error seldom changes more than two tenths of a second from one day to the next.

In July, the mean-time clock, Bond 394, stopped, after sending the signals continuously for four years. It was kept in use, however, till October, when it was dismounted and thoroughly repaired. Meanwhile, from October 7 to October 21, the time-signals were sent by the clock of Messrs. W. Bond & Son, in Boston. It is hoped that hereafter it will not be necessary to take this course, as the sufficiently exact regulation of a clock so far from the Observatory proved to be a troublesome and laborious undertaking. In August, the standard sidereal clock, Frodsham 1327, was cleaned and removed to the new brick vault under the west Equatorial. For a period of twenty-five days, beginning August 30, during which it was left wholly undisturbed, its performance was remarkable both for the uniformity and minuteness of its rate. Its error did not vary two tenths of a second on the thirty-two occasions on which it was compared with the stars.

Various ingenious devices have been adopted by Mr. Edmands for use in the Time Service. Among others may be named those for making a single clock run two independent observing circuits, without the use of relays, and without interference of the observations. Spark arresters have been introduced, that on the

standard clock being a sounder which gives the breaks of the clock without those of the observer. Another sounder gives the time-signals uninterrupted by the five-minute break. Experiments are in progress with a view of improving the methods of distributing standard time. One of the most important of the proposed improvements is a contrivance by which the signals may be delayed by any desired fraction of a second without affecting the clock. An error in the signals may thus be corrected without interference with the pendulum. By this means many variations in the rate of the clock may be prevented, and its performance proportionally improved.

The time-ball has been dropped correctly on 322 days at twelve o'clock by telegraph. Owing to repairs to the roof of the building, it was not dropped during an interval of thirty-five days. On five days it was dropped at twelve o'clock by hand. On two days it failed to drop at twelve, and was dropped five minutes later, according to the rule ; and on one day ice on the mast prevented it from being raised.

Publication. — Volume XIII. of the Annals is now in process of publication, and will be issued as soon as it can be got through the press. It will contain the results of the work with the large telescope, under the direction of the late Professor Winlock, and also the micrometric measurements made up to the present time. Among other subjects treated will be a discussion of the focal length of the telescope and the pitch of the micrometer-screw ; measurements of double stars ; observations of nebulae and of their spectra ; satellites of Saturn, Uranus, and Neptune ; satellites of Mars during the opposition of 1877 and 1879 ; positions of asteroids and comets. An appendix will be added, giving an important list of errata in the zone observations of Professor Bond, kindly furnished by Dr. C. H. F. Peters. As soon as this volume is completed the printing of Volume XIV. will probably be commenced. It will contain the measures made with the meridian photometer.

The papers mentioned below have appeared during the year as communications from officers of the Observatory : —

Variable Stars of Short Period. By Edward C. Pickering. Proc. Am. Acad., xvi. 257. Reprinted in The Observatory, iv. 233, 264, 284.

Large Telescopes. By Edward C. Pickering. Proc. Am. Acad., xvi. 364. Reprinted in Nature, xxiv. 389.

Photometric Measurements of the Variable Stars β *Persei* and DM. 81° 25, made at the Harvard College Observatory. By Edward C. Pickering, Director, Arthur Searle, and O. C. Wendell, Assistants. Proc. Am. Acad., xvi. 370.

On the Probable Period of Swift's Comet. By S. C. Chandler, Jr. Astr. Nachrichten, xcix. 45.

Comet III. 1869. By Edward C. Pickering. Astr. Nachrichten, xcix. 95.

Observations of Last Contact of Solar Eclipse. By Edward C. Pickering. Astr. Nachrichten, xcix. 107.

Elements of Pechüle's Comet (f) 1880. By S. C. Chandler, Jr. Astr. Nachrichten, xcix. 109.

The Comparison of Sirius. By Edward C. Pickering. Astr. Nachrichten, xcix. 219.

On Certain Zodiacal Phenomena. By Arthur Searle. Astr. Nachrichten, xcix. 91, 369.

Objects remarkable for their Colors or Spectra. By Edward C. Pickering. Astr. Nachrichten, xcix. 375.

The Coefficient of Safety in Navigation. By W. A. Rogers. Proc. U. S. Naval Institute, vii. No. 2.

A review of Vol. XI. Part II. of the Annals of the Observatory, by Dr. E. Lindemann, appeared in the Vierteljahrsschrift der Astr. Gesellschaft, xvi. 108. A review of the articles on Variable Stars appeared in the Crónica Científica (Barcelona), iv. 401. Other notices of the Observatory and its work will be found in Nature, xxii. 483, 611; xxiii. 321, 338, 604; in Science, ii. 33, 107, 141, 164, 329, 447, 482; in The Observatory, iv. 81, 113, 116, 154, 245; in Copernicus, i. 139, 140.

With reference to the article on large telescopes, it may be noted that should any addition be made to the equipment of the Observatory, a telescope, mounted according to the method there described, is recommended. It is believed that in no other way could the same amount of work be obtained with a given expenditure. With our present resources, however, it is much more desirable to keep the instruments we now have actively at work than to make any addition to their number.

An important piece of bibliographical work has been undertaken, and placed in charge of Mr. Chandler. The references to obser-

vations of stars of known or suspected variability have been collected, and those of each star brought together. This portion of the work is more than half completed. The comparison stars are then to be measured photometrically, and, finally, a reduction to a uniform system to be made of all the observations of variables of long period.

Various improvements have been made in the condition of the buildings and grounds. Two wooden balconies, having an area of seven feet by seventeen, have been constructed, to replace the small iron balconies to the east and west of the large dome. They are exceedingly convenient for observations made with small instruments or with the naked eye.

In order to connect the previous determinations of longitudes by the U. S. Lake Survey with an established meridian, it was proposed by the Superintendent of the Survey to determine the difference of longitude between Detroit and Cambridge. Facilities for the work were accordingly furnished by this Observatory, and the observations required were made by officers of the Survey. Later in the season, a course of experiments on the force of gravity, by means of pendulum observations, was conducted at the Observatory by officers of the U. S. Coast Survey, who were provided with similar facilities for their work. The West Equatorial was lent for the summer months to Professor S. P. Langley, who used it in observations made on the summit of Mount Whitney, in California.

There are some advantages in an early announcement of proposed investigations, even when the preliminary experiments are not sufficiently advanced to insure their execution. The aid and advice of other astronomers may thus sometimes be secured, and the danger of duplication of work is greatly reduced. No change in the character of the work is proposed, except that an attempt will be made to restrict the work of the large telescope more closely to large pieces of routine work. Such investigations are less likely to be made at observatories where the corps of assistants is smaller, and have a value not attained by detached observations. With the ultimate object of determining the distribution of the light in the spectra of the banded stars, a stellar spectroscope has been ordered of Mr. Hilger, of London. With this it is proposed to measure the position of the principal lines in the spectra of all the banded stars as yet known. A catalogue of these objects has

already been compiled. With the approval and assistance of the Selenographical Society, the photometric determination of the brightness of various points on the surface of the moon has been undertaken. The Society has furnished a list of regions suitable for standards, and the observations may be begun after the decision of some further preliminary questions. The most important of these relates to the age of the moon at which the comparisons should preferably be made. In co-operation with other astronomers, a system of standards of brightness for faint stars has been devised, and measurements of their light will be shortly undertaken.

The new meridian photometer will be used for measuring variable stars and their comparison stars, and also for determining the light of the brighter asteroids. An important piece of work is now under consideration, which would occupy this instrument for several years. During the revision of the Durchmusterung, undertaken by a number of co-operating observatories, and now approaching completion, each of the zones into which the entire region to be surveyed was divided, was somewhat extended northward and southward, so as to overlap the adjacent zones. The object of this extension was to connect the work of the different observers. Hence, the portions of the sky occupied by the overlapping borders of the zones offer a promising field for photometric research, as each determination may be compared with the estimates of magnitude made independently by two observers, with the Durchmusterung itself, with the zones of Argelander and Bessel, and with various other authorities. The number of stars to be measured is estimated at about six thousand, and the time required for the observations with the new meridian photometer would be at least three years.

EDWARD C. PICKERING, *Director.*

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REPORT.

To the President of the University:

Sir, — By the death of Mr. Robert Treat Paine during the past year the Observatory of Harvard College has lost one of the oldest of its friends, well acquainted with the theory and practice of several departments of astronomy, and always deeply interested in the work of this institution. He was an assiduous computer and observer of astronomical and meteorological phenomena, and a member of the Visiting Committee of the Observatory from the time of its first organization, forty years ago. He has perpetuated his services to his favorite science by the bequest to this Observatory of his entire fortune, amounting to more than a quarter of a million of dollars. Upon the settlement of the estate, one half of this sum will become immediately available.

The resignation of another of the original members of the Visiting Committee, Mr. J. Ingersoll Bowditch, is a matter of extreme regret. His services to the Observatory have been continuous, and without his active aid and advice no important steps have been taken in the extension of its work, which has frequently been rendered possible only by his exertions.

During the year the work of which is to be described in the following paragraphs, the resources of the Observatory have been materially diminished, owing to circumstances stated in the last report. It was there mentioned that no means were available for retaining the services of five of the assistants previously employed. But the salary of one of these assistants for another year was soon after provided by means of a subscription undertaken by some of his colleagues, who furnished a part of the required sum from their own scanty means. Without this relief, it would have become necessary to interrupt the regular use of the large telescope in order to continue work with the meridian instruments. As it is, the reduction in the amount of work carried on is much less than would have been expected; but this result is due to extraordinary efforts on the part of the observers, who have performed without assistance the work in which they were previously aided by recorders. This has required an increase in the time spent in observation, and has rendered the work much more

laborious. While this evidence of enthusiasm and devotion to science is most gratifying, it is obvious that it cannot long be continued without injury to health. Indeed, the effects of over-fatigue and exposure during the long, cold nights of last winter were manifest in more than one instance.

East Equatorial.

Eclipses of Jupiter's Satellites. — Photometric observations of these eclipses have been continued upon the system adopted in 1878. In all, three hundred and nineteen eclipses have now been observed, thirty-five since the end of October, 1884. The original plan contemplated the prosecution of the work through an entire revolution of Jupiter around the Sun, more than half of which has already been completed. The importance and extent of this work has made it advisable to delay the adoption of a definite plan of reduction until a sufficient amount of experience had been gained; but there is now no reason to defer the consideration of this subject.

Revision of Zone Observations. — The reduction of the observations of the stars between the declinations + 0° 50′ and + 1° 0′ has been carried on. To determine the scale of the wedge photometer employed in the work, the constants of the instrument have been photometrically examined, and the initial point of the scale for each evening of observation has been determined by means of the stars in each series which also occur in the working list of the meridian photometer. In the entire zone there are about three hundred such stars, all of which have now been measured with the meridian photometer. The magnitudes of the fainter stars observed in the zone with the wedge photometer have been recomputed by the aid of these data. The work of the wedge has thus been made homogeneous with that of the meridian photometer.

Revision of DM. Magnitudes. — The observations of DM. stars between the declinations + 49° 50′ and + 50° 0′, which were begun with the wedge photometer during the previous year, have been completed, as well as a similar series between + 54° 50′ and 55° 0′. The resulting magnitudes have been computed, as in the case of the zone between + 0° 50′ and + 1° 0′, by means of the stars occurring in these zones which are also under observation with the meridian photometer. It is desirable that similar observations should be made in other zones at intervals of 10°. This would extend the scale of the meridian photometer about one magnitude, and would furnish means for determining the scale of the Durchmusterung between the magnitudes 9.0 and 9.5.

The extensive use thus made of the wedge photometer seems to show that the instrument used here is not capable of the great degree

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of precision which is claimed for that employed by Professor Pritchard. To determine whether this difference is due to the form of the instrument, Professor Pritchard was requested and has kindly consented to superintend the construction for this Observatory of a wedge photometer made upon his plan.

Standards of Stellar Magnitudes. — The photometric observations of faint stars selected as standards of magnitude in twenty-four regions following bright stars, and mentioned in previous reports, have been provisionally completed. A few of these stars were bright enough to be observed with the meridian photometer; but most of them were observed with the East Equatorial, with the aid of the wedge photometer or of Photometer I. The results have been published in the report to the American Association for the Advancement of Science by the committee in charge of the subject of stellar magnitudes.

Comparison Stars for Variables. — Another extensive investigation begun with the wedge photometer is the determination of the magnitudes of stars which have been used as standards of comparison for variable stars. Besides the stars of this class named in published works, many others, employed in observations not yet published, have been added to the list. Observers of variable stars are requested to communicate to this Observatory the comparison stars employed by them, and not identical with those contained in published lists. When these comparison stars are sufficiently bright, they are measured by the meridian photometer. Their magnitudes, thus determined, serve as a basis for the measurement of the fainter stars by the wedge. Two observations of each star not determined by the meridian photometer, and of a sufficient number of the others, are made with the wedge on each evening when the region occupied by the comparison stars of any particular variable is observed. Two complete observations of this kind, made on different evenings, are regarded as sufficient; but when moonlight or other causes render the work of either evening imperfect, it is repeated on a third evening. Some incidental attention is also paid, during this work, to enlarging the lists of comparison stars when they can thus be better adapted for future use.

Temporary Star in the Nebula of Andromeda. — This remarkable object, as well as a series of comparison stars selected for it, was repeatedly observed with the wedge photometer immediately after the announcement of its discovery. It is still occasionally observed. It is proposed to determine photometrically the brightness of the stars with which it has been compared by observers at other stations, so far as these are made known.

Comets. — These objects have occasionally been observed as in former years, chiefly by Mr. Wendell. The observations have been confined to special times when they would be of most immediate value. Comet 1884 III. (Wolf) was observed on one night; two others, discovered by Barnard and by Brooks, were respectively observed on seven and on four nights.

Spectra and Color of Stars. — The observations upon the spectra and color of stars have been completed upon the restricted plan indicated in the last report, but are not as yet reduced. It is probable that photography will soon afford a more satisfactory solution of this problem. The work of the East Equatorial in this respect, and also in some others, has been considerably diminished during the year by the frequent employment of the observers in recording the observations made with the meridian photometer, since the diminished resources of the Observatory did not permit the engagement of special assistance in the work of recording.

Meridian Circle.

The work done with this instrument during the year has been more varied in character than usual, while its amount has been somewhat diminished by the financial necessity of dispensing with an assistant to the principal observer. A considerable portion of the year has been occupied with the investigation of the errors of the East Circle of the instrument. This work is now completed. The spaces of 30°, 15°, 5°, 1°, have been independently investigated; the labor thus performed is equivalent to that of reading a single microscope about forty thousand times.

In order to perfect the revision of the zone between $+50°$ and $+55°$, some additional observations were found to be desirable, when the reduction of the preliminary revision, finished in August, 1884, had been completed. The doubts remaining to be settled chiefly related to possible errors of an entire minute in the circle readings, and to unusually large discrepancies between the positions here obtained and those given in the Durchmusterung. The new revision was begun January 8, 1885, and will be completed with six more nights of observation. Each star concerning which any doubt existed has ordinarily been twice observed. The whole number of observations is 937.

The observation of a polar catalogue was begun April 30, 1885. The working list includes 30 fundamental stars and 153 others. For the present year, the plan of the work requires two observations of each star at each culmination. The number of observations hitherto made is 384.

A series of 275 observations was carried on simultaneously with corresponding observations made with the almucantar, in order to compare the results given by the two instruments, and to test the precision of the Clark level attached to the meridian circle.

Observations of particular stars have also been made at the request of Dr. Auwers, Dr. Elkin, and Professor Holden. These observations are respectively 173, 24, and 12 in number. The first two series will furnish material for the determination of heliometer constants, and the last for the reduction of latitude observations.

The total number of observations with the meridian circle is accordingly 2808, including 1003 observations of fundamental stars employed in the revision of the zone and in the polar catalogue.

The reduction of the first revision of the zone observations is complete. The observations of fundamental stars made up to last October, during the second revision, are also reduced. The reduction of the miscellaneous observations is finished, with the exception of a few of those made at the request of Dr. Auwers.

The report of the longitude operations between Cambridge and Montreal in the summer of 1883 has been completed. It will appear, in connection with the report of Professor McLeod, in the forthcoming volume of the Proceedings of the Royal Society of Canada.

Meridian Photometer.

The number of series of observations made during the year by Mr. Wendell and myself is 202, an increase of 61 over those of the previous year; and the number of separate settings somewhat exceeds 50,000, against 27,500 for the previous year. The accordance of the results continues satisfactory. The average deviation of the separate measures of the standard circumpolar stars, expressed in magnitude, is 0.12. Although this exceeds the corresponding result for the previous year by only a single hundredth of a magnitude, the difference may not be purely accidental, but have its cause in the variability of one or more of the standard stars.

The list of objects to be observed with the meridian photometer has been somewhat extended. The stars first selected from the Durchmusterung for observation were those the magnitude of which had been estimated at each of two observatories during the zone observations carried on during recent years under the general direction of the Astronomische Gesellschaft. To increase the regularity of distribution of the stars observed, other zones of 20′ in width were added, so that the entire series includes zones at intervals of five degrees from the equator to the pole. The middle of each zone is defined by the parallel of declination at 0°, + 5°, + 10°, etc.

This system ensured a regular distribution of the stars to be observed, and supplied a sufficient number of stars of the eighth and ninth magnitudes to be employed in the determination of the various scales of magnitude in use. The number of stars between the sixth and eighth magnitudes, however, hardly seemed large enough for this purpose. To supply the deficiency, the zones were extended to a width of 60′ for for stars of the magnitudes 7.0 to 7.9 inclusive, and to a width of 120′ for those of the magnitudes 6.1 to 6.9 inclusive. The magnitudes of the stars brighter than these have already been published in Volume XIV. of the Observatory Annals.

The miscellaneous work with the meridian photometer, mentioned in the last report, has been continued. Two special features of this work have already been mentioned in connection with the observations made with the wedge photometer.

Almucantar.

Mr. Chandler has continued his observations with this instrument, which in his hands has exhibited a surprising efficiency and accuracy, fully confirming the anticipations expressed in the last report. The work of observing was suspended after July 1, to allow time for the reduction of the previous observations, the number of which between November 1, 1884, and July 1, 1885, was approximately one thousand. The following subjects have been investigated: right ascensions of circumpolar stars; declinations of stars near the equator; the latitude of this Observatory; effects of personal equation at different declinations, obtained by observers with the meridian circle and with the almucantar. The positions obtained by means of the almucantar have such a precision as to have already led to the detection of errors in the accepted places of several important stars occurring in fundamental catalogues, and generally regarded as accurately determined.

Miscellaneous.

Variable Stars. — Messrs. Parkhurst, Eadie, Hagen, and Zaiser, have continued their valuable coöperation with this Observatory throughout the year. The large and rapidly increasing number of observations of variable stars secured by these gentlemen will form a highly important source of information with regard to such objects. Steps have been taken to provide for the reduction of these observations, which will require however the photometric determination of the brightness of the comparison stars before much progress in it can be made.

The request to astronomers made last year in the pamphlet "Recent Observations of Variable Stars" was kindly complied with by the

principal observers of variable stars in Europe and America. Their names, together with a summary of their work, are given in the pamphlet "Observations of Variable Stars in 1884," which was published by this Observatory early in 1885.

Stellar Photography. — By the aid of the Bache Fund an important investigation has been undertaken in stellar photography. A Voigtlander portrait lens of 8 inches aperture and 44 inches focus has been reground and mounted equatorially by Messrs. Alvan Clark & Sons. It is driven by clockwork, having a Bond spring governor controlled electrically by a sidereal clock substantially mounted in the clock-room of the Observatory. A wide field of work is opened with this instrument. Many photographs have been taken of the trails left by a star when the telescope is not driven by clockwork. An equatorial star will leave its mark in this way when no brighter than the sixth magnitude. Much fainter polar stars will leave an impression, since their motion is slow. Stars as faint as the fourteenth magnitude have thus been photographed without clockwork. The positions of faint polar stars may be determined with great accuracy from their trails, which are very well defined and minute. They also appear to afford an excellent measure of stellar brightness. Attempts have also been made to prepare star-charts by photography. Regions 5° square will bear an enlargement of three times, and by photolithography will furnish charts of the dimensions and scale of those of Peters and Chacornac. The most striking results have been obtained with stellar spectra. Replacing the slit spectroscope by a large prism placed in front of the lens, photographs have been obtained of stars as faint as the eighth magnitude in which lines are shown with sufficient distinctness to be clearly seen in a paper positive. As all the stars in a large region are thus photographed, more than a hundred spectra have been obtained on a single plate. Mr. William H. Pickering has rendered important aid in this investigation, especially in the photographic process. A portion of Mr. Pickering's investigation on the possibility of photographing the solar corona without the aid of an eclipse was also conducted here. The conclusion thus reached was that, unless the effect of the air could be reduced three hundred times, no satisfactory results could be obtained with our present means. The details of this investigation will be found in *Science* VI., 362, 387.

Time Signals. — The time service of the Observatory has not fully succeeded at all times during the year in maintaining the high standard of former years. Inevitable interruptions and delays have occurred from various causes, among which may be specially mentioned the want of a duplicate mean time clock and the increasing number

of telephone and telegraph wires used in Boston, with its natural consequence of frequent interference with wires previously in use. By persevering exertion, however, a satisfactory system for transmitting the signals has now been established. Much delay also occurred in making the arrangements necessary for the new time-ball, which was not brought into operation until October 1, since which time it has been regularly dropped. It is made upon the plan adopted by the United States Government offices, and its cost has been largely provided for by an appropriation made by the city government of Boston.

The list of subscribers to the time signals remains nearly the same as that given in the last report, the most important accession being that of the Boston and Lowell Railroad.

Telegraphic Announcements. — The telegraphic distribution of important astronomical discoveries or data has been continued during the year under the management of Mr. Ritchie, as before. Announcements have been made of the discovery of nine asteroids, five comets or suspected comets, and one new star. There have been sent to Europe or received therefrom twenty cable messages, and the number of telegrams sent in this country was two hundred and seventy. The Associated Press has been regularly notified of the facts thus distributed, and the information has been widely spread by means of the newspapers.

Height and Velocity of Clouds. — This subject has been studied during the year by Professor W. M. Davis, assisted by Mr. A. McAdie, who stationed themselves respectively on the east balcony of the Observatory and at the Jefferson Physical Laboratory. These stations were connected by telephone, and the observers were thus enabled to decide upon suitable portions of clouds for simultaneous observation with wooden altazimuth instruments. About three hundred pairs of measures were made in the spring of 1885 with generally satisfactory results. The altitudes determined varied from 2000 to 25,000 feet; for altitudes less than 8000 feet the variation between the measures was generally within five per cent of the height. In one instance, consecutive observations of a single cumulus cloud showed its base to be 4500 feet high; its summit rose from the height of 6750 to that of 7300 feet at the rate of 200 feet a minute, while the cloud drifted to S. 43° E. at the rate of 27½ miles an hour.

Additional Researches. — Several investigations have been carried on by the aid of the Rumford Fund. They include the determination of the amount of light reflected specularly and diffusely by various substances at different angles; the absorption of the wedge of shade glass used as a photometer for the large equatorial; the opacity of a

series of photographic images employed as standards by Mr. W. H. Pickering in his photographic researches. The atmospheric refraction at large zenith distances was determined by several series of observations of the Sun and of *α Bootis* when setting. Various measures were also made of the amount of the atmospheric polarization.

During the summer over a thousand vertical angles were measured from the summits of Mt. Moosilauk and of Mt. Mansfield to determine the heights of the mountains of New Hampshire and Vermont by the method of geodetic levelling.

For three quarters of an hour after the explosion of Flood Rock was expected to take place, Professor Rogers watched a mercury surface with a microscope to detect the effect of the earthquake wave. Disturbances occurred beginning $3^m\ 14^s$ after the explosion and lasting nearly three minutes, which were apparently due to this cause. Various experiments were afterwards made to show that no local disturbance could have produced the same effect. This appears to be far the greatest distance to which the effects of an artificial explosion have been traced.

Exhibition of Instruments. — To permit the examination by the public of apparatus which would not generally be readily accessible, several instruments not required for immediate use were sent to the exhibition of the Massachusetts Charitable Mechanics' Association. Gold medals were awarded to two of these instruments, the meridian photometer and the almucantar.

Publications.

The principal publications of the year were Volume XIV., Part II. of the Observatory Annals, and the Catalogue of 1213 Stars which will form a part of Volume XV. The second part of Volume XIV. contains a discussion of observations by ancient and modern observers to determine stellar magnitudes, with an explanation of the methods by which the final results of these observations as given in Part I. of the same volume were ascertained. It also investigates various sources of error likely to affect the determination of the brightness of stars, and compares the general result reached with the meridian photometer and those obtained by other means.

The Catalogue of 1213 Stars, prepared by Professor Rogers, contains the results of observations which he carried on with the meridian circle from 1870 to 1879. The catalogue contains accurate places of many stars which, although moderately bright, had previously been only imperfectly observed; and also furnishes means for the more precise determination of the places of numerous fundamental stars.

The publications named below have appeared either as official communications from the Observatory or as papers prepared by its officers individually: —

Thirty-ninth Annual Report of the Astronomical Observatory of Harvard College.

Observations of Variable Stars in 1884. By Edward C. Pickering. Proc. Am. Acad. of Arts and Sciences, xx. 393.

A Photographic Study of the Nebula of Orion. By Edward C. Pickering. Id. xx. 407.

Third Report of the Committee on Standards of Stellar Magnitude. Edward C. Pickering, Chairman. Proc. Am. Assoc. for the Advancement of Science, 1885, p. 1.

Photometric Observations of Neptune at the Harvard College Observatory. By Edward C. Pickering. The Observatory, viii. 111.

Photometric Observations of Ceres (1), Pallas (2), and Vesta (4) at the Harvard College Observatory. By Edward C. Pickering. Id. viii. 238.

On a hitherto unexplained observation by Capt. Gilliss. By S. C. Chandler, Jr. Sidereal Messenger, iii. 315.

Photometric Measurements at the Harvard College Observatory of the Faintest Stars in the Charts constructed by Palisa. By Edward C. Pickering. Id. iv. 133.

Possibility of Errors in Scientific Research due to Thought Transference. By Edward C. Pickering. Amer. Soc. Psychical Research, i. 235.

Elements of Comet 1884 (Wolf). By S. C. Chandler, Jr. Astronomische Nachrichten, cx. 143.

Orbits of Meteors. By O. C. Wendell. Id. cxi. 189.

Dr. Gould's Star in Sculptor. By S. C. Chandler, Jr. Id. cxi. 333.

On the Latitude of Harvard College Observatory. By S. C. Chandler, Jr. Id. cxii. 113.

Comet-Meteor Radiants. By O. C. Wendell. Id. cxii. 321.

On the Right Ascensions of certain Fundamental Stars. By S. C. Chandler, Jr. Id. cxii. 381, cxiii. 17.

On the determination of the absolute length of eight Rowland Gratings. By W. A. Rogers. Proc. Am. Micros. Soc. for 1885, p. 151.

The Microscope in the Workshop. By W. A. Rogers. Proc. Soc. of Mechanical Engineers, Boston meeting, 1885, p. 1.

An Examination of the Standards of Length constructed by the Société Génevoise. By W. A. Rogers. Proc. Am. Acad., xx. 379.

A Preliminary Examination of Metal Thermometers. By W. A. Rogers. Am. Meteor. Journal, October, 1885, p. 252.

Description of a series of fifty Slides, illustrating the action of a diamond in ruling upon glass, presented to the Royal Microscopical Society of London. By W. A. Rogers. Journal R. Micros. Soc., October, 1885.

On a new form of Section-Cutter. By W. A. Rogers. Proc. Am. Soc. Microscopists, 1885, p. 191.

Additional Observations confirming the Relation: Metre des Archives = Imperial yard + 3.37027 inches. By W. A. Rogers. Proc. Assoc. for the Advancement of Science, 1884, p. 117.

To avoid the diminution of astronomical work, many desirable improvements in the general condition of the Observatory have been postponed. They will be undertaken whenever the financial condition of the institution will permit this to be done. Among them may be mentioned new facilities for the use of the large telescope, including probably the entire remounting of the instrument; the arrangement of books in the library, the binding of many valuable works, the provision of new shelving, and the completion of the card catalogue; the improvement of the drainage of the building and grounds and the protection of the woodwork by painting. A still more pressing need than any of these is the publication of material nearly ready for the press, which would occupy several volumes and is now exposed to the risk of destruction by accident. It is to be hoped that this want, at least, may be soon supplied.

EDWARD C. PICKERING, *Director*.